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UCRL-JC-152490

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August 22, 2003

2003 Third International Conference on Inertial Fusion
Sciences and Applications, Monterey, CA
September 7-12, 2003

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This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Modeling the effects of IR heating on the fuel layer symmetry in a cryogenic NIF ignition target

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We use thermal conduction models to investigate the effects of tailored IR heating on the fuel layer symmetry within a target capsule supported inside of a National Ignition Facility (NIF) hohlraum. We calculate the layer thickness profile that would result from the IR heat distribution alone and in combination with additional temperature shimming of the cylindrical hohlraum wall. We use the same model to study the effect of convection within the high density tamping gas in the hohlraum. A seven-region model was developed to evaluate how effective additional thin film convection barriers may be in damping convection with the higher power dissipation introduced by IR heating.

Introduction

Some indirect-drive targets¹ for ignition testing in the National Ignition Facility (NIF)^a will have infrared (IR) enhanced² fuel layers. IR enhancement of DT fuel layer consists of increasing the power dissipation within the fuel layer by illuminating the DT layer

^a Currently being constructed at the Lawrence Livermore National Laboratory. The NIF will be a 192 beam frequency-tripled Nd:glass laser system with on-target energy and power of 1.8 MJ and 500 TW, respectively.

with IR at a wavelength that is absorbed by the ice layer. This has several advantages: one, it smoothes the fuel free surface thus decreasing the amplitude of the Raleigh-Taylor instabilities seeded by the solid vapor interface. Two, it allows us to decrease the average ice temperature, which decreases the fuel vapor pressure and increases target gain. Three, it decreases the layer formation time constant, which allows us to evaluate and control layer quality several times faster. However, the target capsules themselves also absorb significant amounts of IR energy. The energy absorbed by the capsule wall does not contribute to the fuel layer enhancement, but the heat released in the capsule as well as in the layer flows to the hohlraum wall through a 50-50 mole% mixture of H_2 and He, which serves as a cooling medium and tamping gas. The additional heat flow through the high density (1 mg/cc) tamping gas will cause convection cells to form³ and disturb the delicately balanced thermal environment surrounding the target capsule. To alleviate this problem, we have designed hohlraums with very thin (1000 angstroms) films that, located strategically within the hohlraum, impede the formation of high velocity, convection flow cells. In this paper, we describe a hohlraum design that subdivides the tamping gas volume into seven separate regions as depicted in Figure 1, to reduce the effect of convective flows on the target layer symmetry. An axis-symmetric model of this hohlraum design is constructed and results of both, thermal and hydrodynamic analysis are presented.

Seven region hohlraum

In the seven-region hohlraum model, we introduced two additional films, which subdivide the large upper and lower regions roughly in half. These two regions located between the LEH and the first set of convection damping films had the highest flow

velocity in the five-region hohlraum model³ previously analyzed. By reducing the flow velocity in these regions, we expected to reduce the amplitude of the dominant P_1 mode in the capsule thermal environment. We optimized the axial position of the second set of convection damping films by equalizing the velocity in the subdivided regions. This equalization procedure resulted in the lowest overall peak velocity for all regions. We also found that the new damping films location are sensitive to a 0.25 mm axial shift, and peak velocities will increase by approximately 20% to 27% depending on whether the films are moved closer to the capsule or closer to the LEH, respectively. The peak flow velocity decreased by more than a factor of five (from 1.06 to 0.115 mm/sec) within tamping gas when compared to the 5-region hohlraum model. The plot in Figure 1 shows the velocities within the seven-region hohlraum model and the optimized location of the damping films. The optimized location of the films is closer to the capsule, which places them in the higher thermal gradient area of the subdivided regions.

Modeling analysis and conduction results

Thermal analysis (conduction limit) of the seven region model with IR layer enhancement were performed with the finite element code COSMOS^b. The IR power dissipation was scaled to match 1x and 3x the nominal power dissipation due to β -decay within the ice layer. The power dissipation within the target capsule⁴ was obtained from an optical non-sequential ray-trace model developed by one of us (Kozioziemski) to determine the power dissipation in both, the capsule and the ice layer as a function of the

^b Studies were carried out with the thermal module of the COSMOS/M Finite Element Analysis Program from Structural Research and Analysis Corporation.

illumination geometry. The power dissipation profiles generated by the optical model fitted to the first six Legendre modes and remapped to the layer and capsule areas of the COSMOS model provided the required heat source. After the model was executed, the resultant temperature profiles of the ice layer and the capsule inner and outer surfaces were then exported to the MathCAD analysis program⁵ we use to calculate the layer thickness. Since mode 2 can be successfully reduced by properly pointing the IR illumination without the need for thermal shimming, the conduction model results were used to modify the input power mode 2 profile until the contribution of mode 2 was essentially nullified. Reducing the mode 2 amplitude, we note (refer to Figure 2) that with one Q_{DT} of IR power, the thermal asymmetry of mode 4 contributes less than 75 μK . At three Q_{DT} of IR power, mode 4 asymmetry exceeds 200 μK (see Figure 3), and will have to be reduced. This reduction in mode 4 may be accomplished by using four rings IR heating in the hohlraum wall (instead of the current two), and controlling their relative amplitudes.

Convection model results

For nominal damping gas density of 1 mg/cc, convection flow velocity (shown in Figure 4) increases proportionally by more than an order of magnitude as the IR power dissipation within the capsule increases by the same amount. The power dissipated in the fuel layer increases only by a factor of two, but the large increase in total power is dominated by the large (10x) increase in the power dissipated within the capsule. However, larger increases in the IR power do not lead to proportional increases in the flow velocity as shown in Figure 4. An increase in the total power dissipation by an additional factor of three only increases flow velocities by less than 15%. This is a clear

indication that reducing the size of the convection cell that can form within the tamping gas increases viscous damping and limits the growth of the maximum peak velocity. With convection, the odd modes grow fastest with mode 1 dominating the spectrum as shown in Figure 6. Since we can readily reduce the mode one amplitude by changing the temperature at the cooling rings, only modes three and five are of concern.

Conclusion

We have shown that the use of thin film barriers judiciously located within the tamping gas can reduce the peak flow velocity even at relatively high power (10x – 30x) the nominal β -layer power. It is also evident the peak flow velocity growth versus power can be effectively arrested. For the higher power cases, we will have to optimize the shape of the capsule support films, to help reduce convection in the central region if we need to keep the tamping gas density at the nominal one mg/cc. Conversely, if we can reduce the density of the tamping gas, we will simultaneously reduce all of the convection related effects proportionately.

¹ J. J. SANCHEZ and W. H. GIEDT, "Thermal Control of Cryogenic Cylindrical Hohlraums for Indirect-Drive Inertial Confinement Fusion," *Fusion Technol.*, **36**, 11, 346-355 (1999).

² D. Bittner, *Fusion Technology needs checking* **41**, 100 (2002).

³ J. J. SANCHEZ and W. H. GIEDT, "Thin Films for Reducing Tamping Gas Convection Heat Transfer Effects in a NIF Hohlraum," *Fusion Science & Technol.*, in press; Sophie Charton, *Fusion Sci.Tech.* **41**, 242 (2002).

⁴ B. J. Kozioziemski, *Fusion Science and Technology* **1**, 1 (2002).

⁵ J. J. Sanchez and W. H. Giedt, Predicting the Equilibrium Deuterium-Tritium Fuel Layer Thickness Profile in a NIF Hohlraum Capsule, *Fusion Science and Technology*, Proceedings of the 15th Target Fabrication Specialists Meeting, to be published.

Fig 1

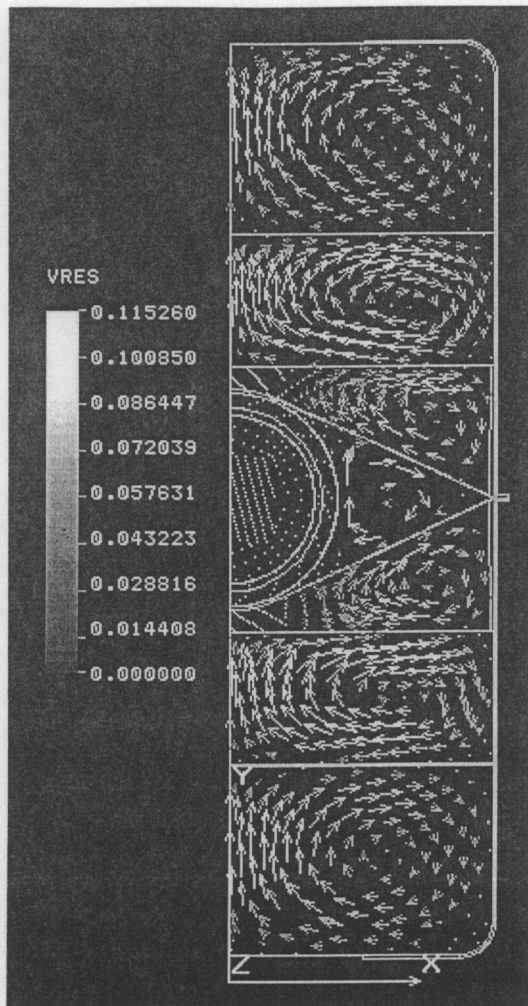


Fig 2

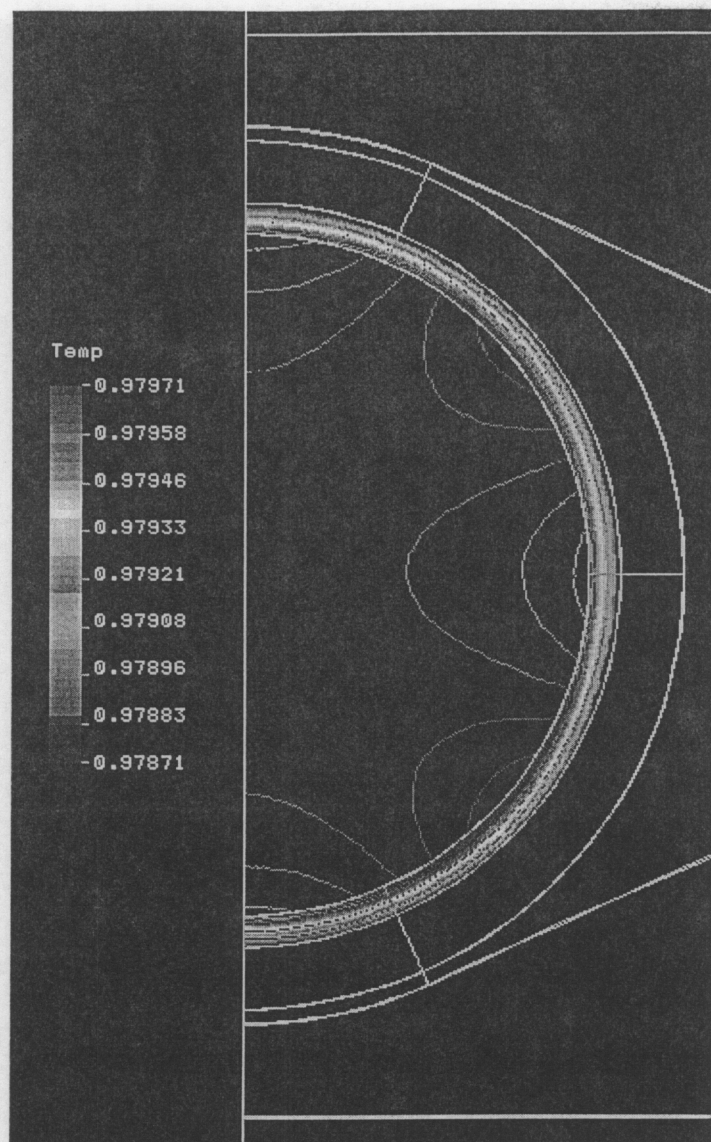


Fig 3

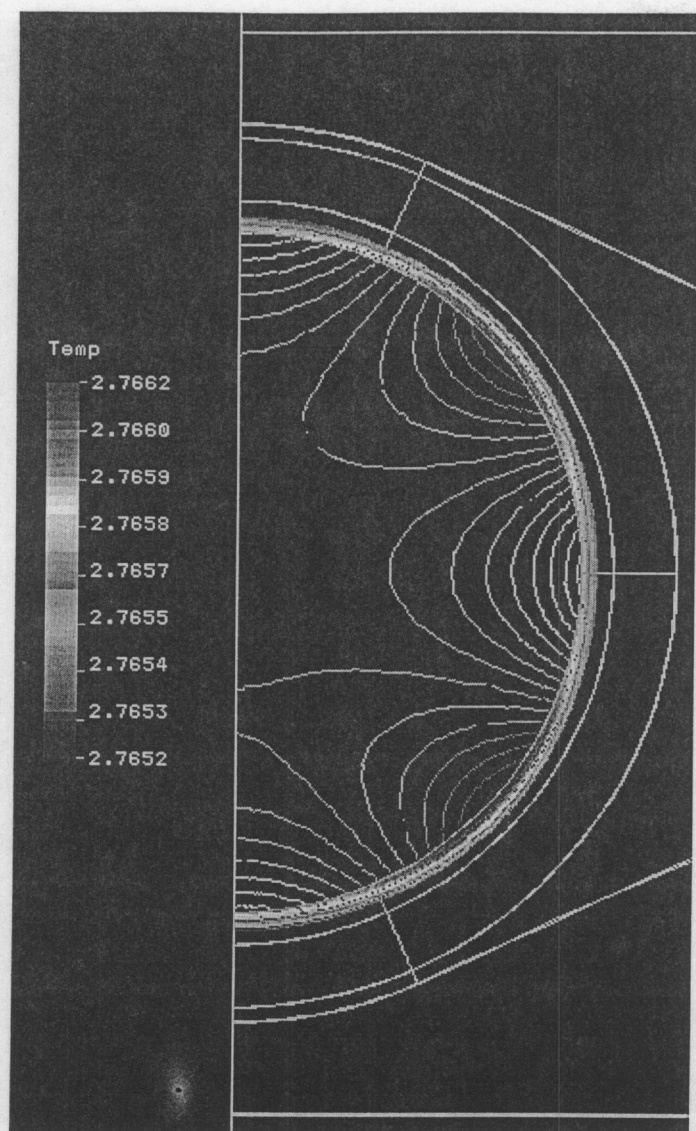


Fig 4

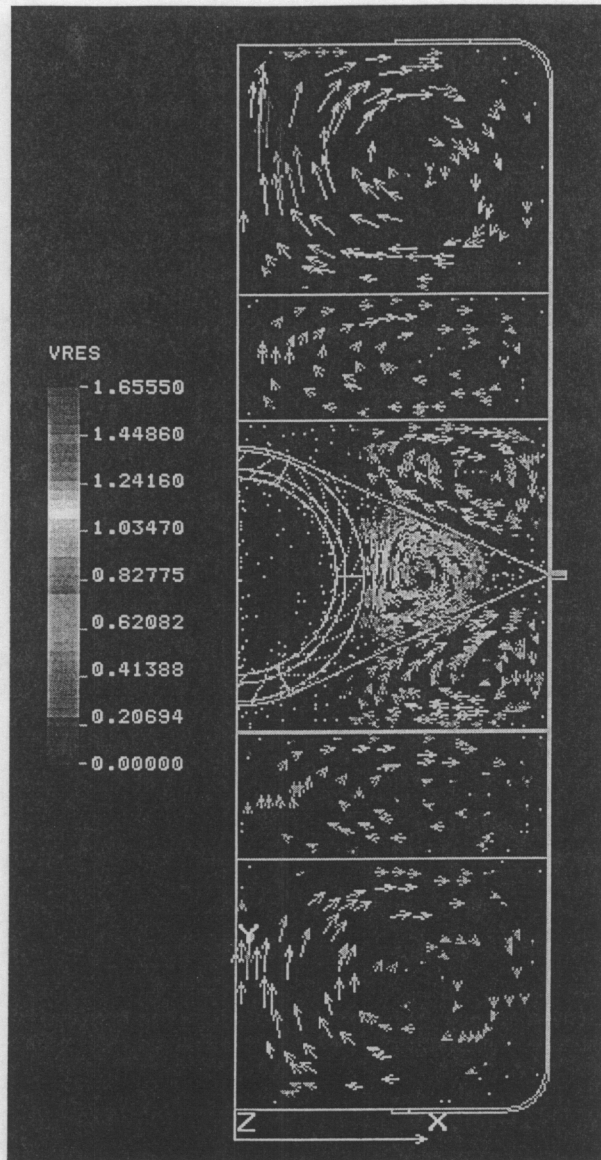


Fig 5

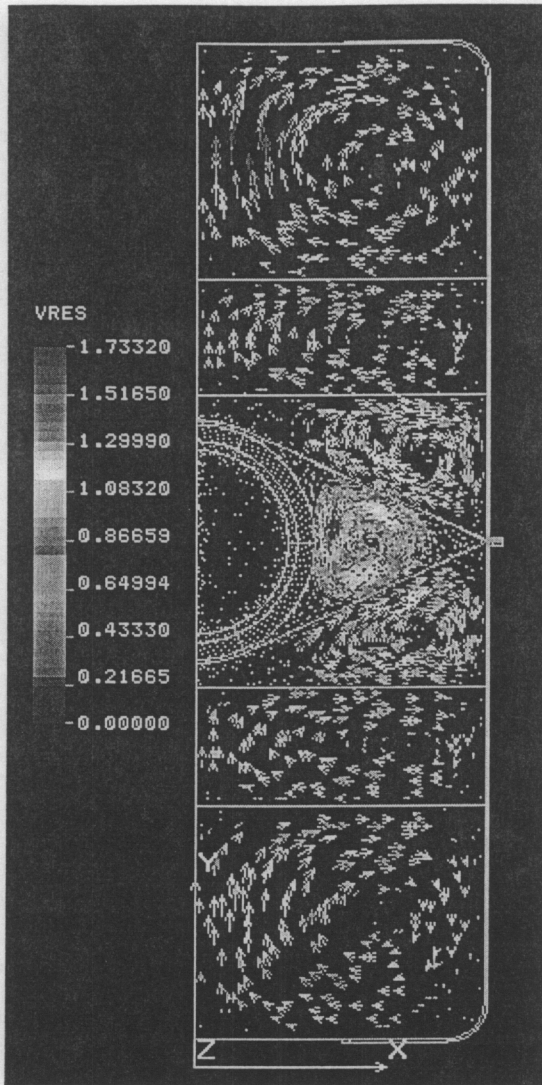


Fig 6

